Development Status and 1U CubeSat Application of Busek's 0.5N Green Monopropellant Thruster

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Summary

- Busek has developed a flight-weight, 0.5N AF-M315E thruster based on an innovative, patent-pending catalyst technology. Catalyst pre-heat requirement was determined at 12W for 8min (1.6W-Hr energy input).
- The 0.5N thruster has proven performance of >220sec vacuum Isp at full thrust. Both steady-state and pulsed firings were demonstrated. Minimum impulse bit around 0.036N-sec.
- The thruster is paired with a novel piezo-actuated microvalve that weighs 67g and consumes less than 200mW power. The valve is fully-welded and has all-titanium wetted parts for long-term propellant compatibility.
- The piezo valve is rated for 1200sccm GN_2 max flow and 1.5×10^{-4}sccm GN_2 leak rate. ΔP for nominal 0.5N level AF-M315E flow is <20psid. It has passed shock & vibe and is currently TRL 5.
- A 1U CubeSat green propulsion system is being developed that centered on the 0.5N thruster and piezo microvalve. It features a low-power Post Launch Pressurization System and is capable of 475N-sec total impulse, or 122m/s ΔV for a 3U/4kg CubeSat.

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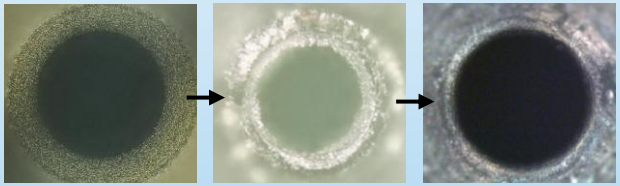
Busek Flight-Weight 0.5N AF-M315E Thruster

- Innovative, patent-pending catalyst
  - Monolithic design without ceramic substrate.
  - Requires no bed plates for containment.
  - Robust; prototype model demonstrated >20min accumulative life w/o performance degradation.
  - Low energy input; pre-heat to ~400ºC ignition temp requires only 12W for 8min, equivalent of 1.6W-Hr.
- High-temp nozzle material
  - Niobium alloy nozzle with protective coating.
  - Inexpensive material selection compared to Ir/Re nozzles, yet effective.
  - Allows 30sec continuous firing at full thrust; longer burns possible.
- Unique high-efficiency nozzle construction
  - Niobium was machined to spec before coating.
  - Coated nozzle throat is rough and requires polishing.
  - Post-processed nozzle consistently achieves 95% cold-gas nozzle efficiency in vacuum; impressive for its micro scale.



View of Nb Nozzle Throat during Construction

FW 0.5N Thruster Firing at Full Throttle in Vacuum

Post-Test View of FW 0.5N Thruster

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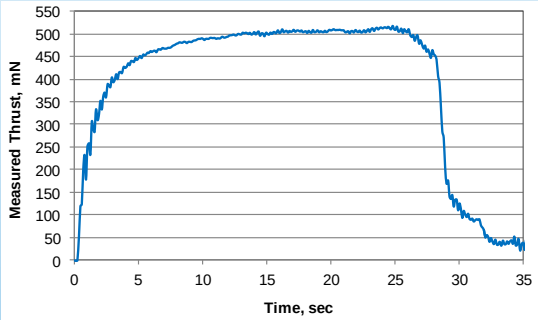
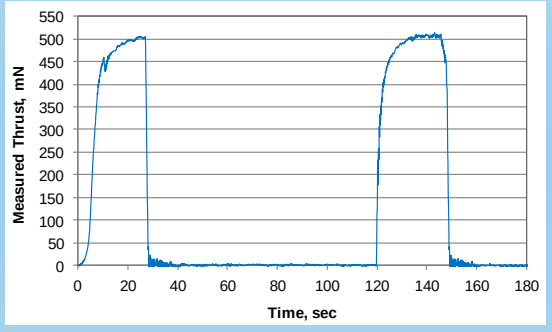
Performance of 0.5N AF-M315E Thruster

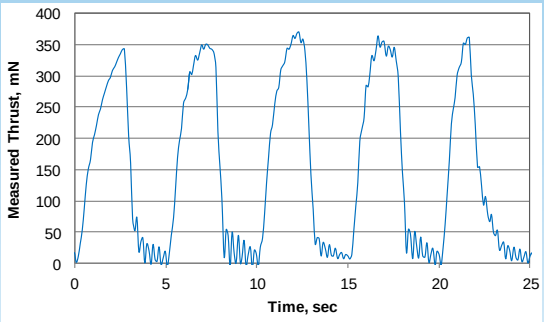
- Hot-firing of 0.5N thruster was conducted in vacuum with a syringe-pump feed system.
- Steady-state test
  - ~25sec duration firings.
  - 223sec Isp measured at 506mN thrust.
  - Time to reach steady-state depends on the nozzle temp at start. Colder nozzle = longer thrust rise.
  - Tradeoff between using inexpensive nozzle material (more thermal soaking due to thicker wall) and thrust rise time.
- Semi steady-state test
  - Two consecutive ~25sec pulses, with 90sec down time.
  - Both pulses reached 500mN.
  - Pre-heat not required for the 2nd pulse.
- Pulsed firing test
  - Pump synchronized with a COTS solenoid valve. Long thrust tail-off due to volume in between valve & thruster.
  - 2.5% to 50% duty cycles, shortest pulse width at 0.5sec.
  - Minimum i-bit at 0.040N-sec (with solenoid valve).



Steady-State Test



Semi Steady-State Test



Pulsed Test with 0.2Hz and 50% Duty(2.5sec on/off)

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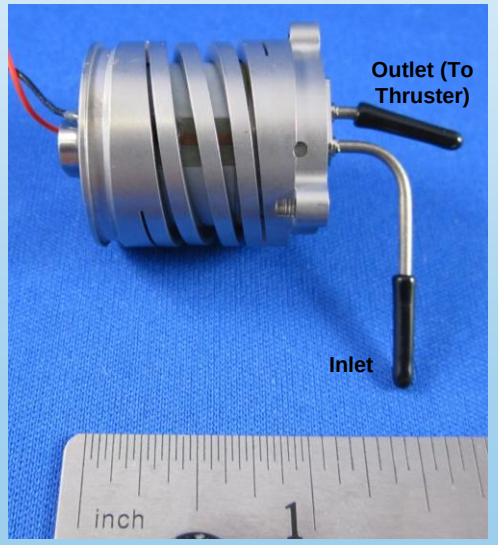
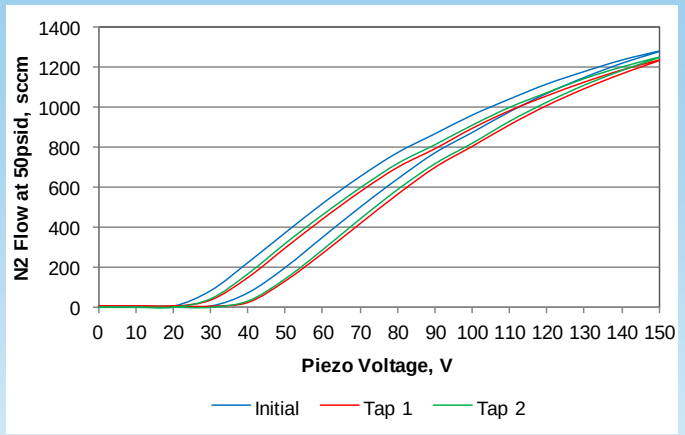
Completion of Piezo Microvalve Development

- Busek's 0.5N AF-M315E thruster is coupled to a novel piezo-actuated microvalve, designed specifically for green propellant use.
- TRL 5, engineering model (EM) microvalve
  - Small footprint and weighs only 67g (vs. >100g for SOA).
  - Requires <200mW to operate (vs. >10W for SOA), via a custom miniature valve driver board.
  - All-welded design w/o elastomer seals; proven up to 400psig without burst.
  - All titanium-wetted surfaces for AF-M315E compatibility; also compatible with many other gas & liquid propellants.
  - Reliable, repeatable & cost effective – a feat considering the actuator has only ~10µm stroke.
  - Demonstrated leak rate of 1.5×10^{-4}sccm GN_2.
  - Demonstrated max flow of 1200sccm GN_2 at 50psid; the opening capability equates to ~20psid when flowing 9.5mL/min AF-M315E (nominal flow for 0.5N thrust).
- Has passed 3-axis shock & vibe test
  - Random vibration, 26G quasi-static load, 20G sine wave and Shock Response Spectrum (SRS) shock.



EM Piezo Microvalve



GN_2 Flow Curve of EM Valve Build #2

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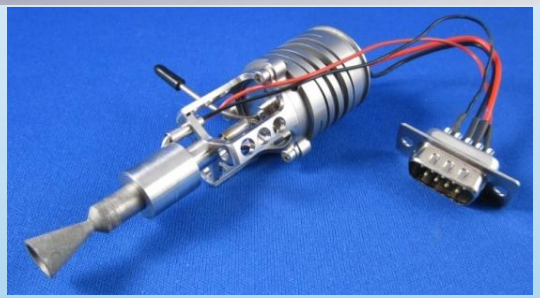
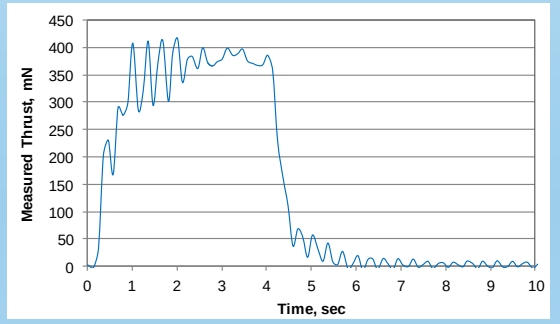
Integrated Thruster-Microvalve Testing

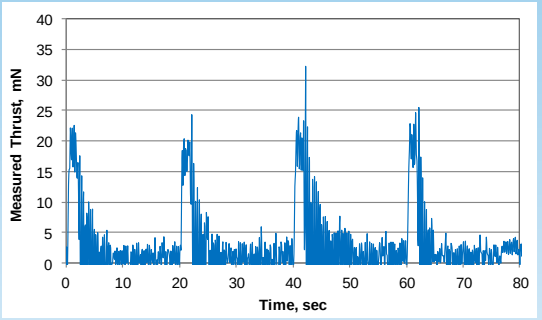
- The 0.5N thruster was integrated with the EM microvalve for combined testing.
- Air within the feed line is a major concern
  - "Vaporlock" issue: AF-M315E is known to have trouble flowing through small orifices in atmosphere, or when there is trapped air bubbles.
  - 1st trouble spot: the 0.5µm filter upstream of microvalve.
  - 2nd trouble spot: microvalve stem only lifts ~10µm.
- Pump-fed, short-duration firing
  - Successful 4sec pulse with quick rise and short tail-off.
  - Large thrust oscillations likely due to air bubbles in the propellant.
- Pressure-fed, minimum impulse bit test
  - Propellant driven by low, 50psia regulated pressure.
  - Four 2sec pulses at 10% duty cycle; highly repeatable with sharp responses.
  - 0.036N-sec minimum i-bit recorded.
- Full duty-cycle workout planned for future work
  - Maintaining air-free feed system is critical to success.



0.5N Thruster with Integrated Piezo Microvalve



A Pump-Fed, 4sec Duration Firing



10% Duty Cycle Test with 50psia Regulated Feed Pressure (Pressure Driven)

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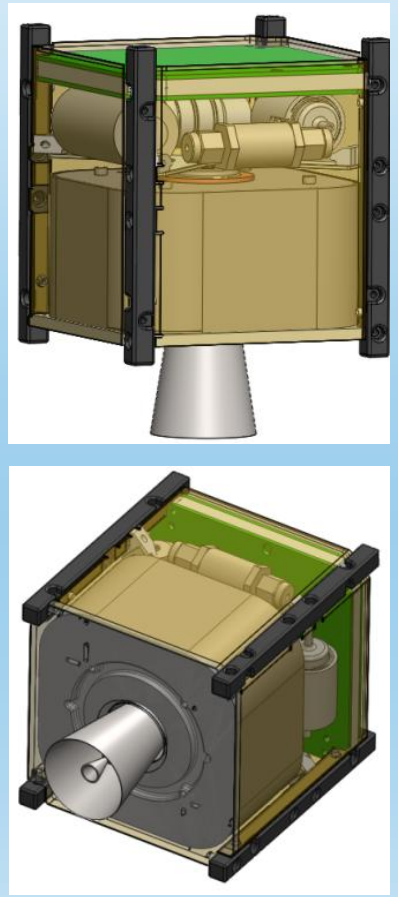
1U CubeSat Green Propulsion System

- Busek is developing an integrated, self-contained 1U green propulsion system
  - Based on Busek's 0.5N AF-M315E thruster and piezo microvalve.
  - Dual-bellows, toroidal propellant tank made of titanium.
  - Weighs 1.2kg wet & capable of 475N-s total impulse (122m/s ΔV for 3U/4kg CubeSat).
  - Pressure and temperature telemetry available.
  - Miniaturized PPU, including microcontroller-based DCIU and high-voltage converters.
  - Just "bolt on" and "plug in".
- Launch completely unpressurized
  - Patent-pending "Post-Launch Pressurization System" that generates inert pressurant gas in space with ~1W input.
  - Makes it safe to store a pre-loaded system on the shelf .
- Simple interface requirements
  - Requires only bus power (15W at any voltage) and one RS-232 communication port.
  - Most of the 15W is needed for thruster's catalyst preheat; otherwise <1W is required during hot-firing operations.



1U CubeSat Propulsion System Concept Based on the 0.5N AF-M315E Thruster

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Conclusion

- Busek's 0.5N AF-M315E green monoprop thruster has achieved 500mN thrust and >220sec vacuum Isp. Both steady-state and pulsed firings (2.5-50% duty) have been demonstrated. Catalyst pre-heat requires only 12W for 8min.
- Busek's piezo microvalve complements the 0.5N thruster with its small footprint and extremely-low power draw (<200mW). Its uniqueness comes from an all-welded, all-titanium wetted design without elastomer seals.
- Both the thruster and the valve have great manufacturability and repeatability, resulting in reduced production cost. Integrated testing was performed with 0.036N-sec minimum impulse bit.
- A 1U green propulsion system based on the 0.5N thruster is being developed.
- Future work includes a full duty-cycle test for the integrated thruster-microvalve, in addition to completing the 1U system design & development.
- The authors would like to thank Mr. Anthony P. Zuttarelli of AFRL/Edwards for sponsoring the 0.5N thruster program, and Dr. Matthew Deans of NASA GRC for sponsoring the 1U system development.

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